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AGRICULTURE

Moisture Transfer to and from Tire Cords Encased in GR-S[1] */

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THE efficiency with which the rubber enveloping the cord in a tire retards the diffusion of moisture into or out of the cord assumes importance because of the dependence of the strength and other mechanical properties of the cord on its moisture content. The matter is doubly significant in the comparison of cotton with rayon tire cords because the effect which absorbed moisture has on the strength of one of these cords is opposite to the effect on the other cord. Generally cotton cords increase in tenacity with increased moisture at least at the lower ranges; while rayons show a sharp decrease as they take up moisture.[4] Thus, depending on the permeability of tire rubber to atmospheric moisture, either type of cord in a tire may be brought to a more or a less favorable condition, merely by the humidity conditions of storage or service. One aspect of the general problem concerns the ability of the outer layers of rubber in a tire to prevent a change in the moisture which is in the cord at the time the tire is molded.

To procure exploratory information on the magnitude of the effects involved it was decided to measure the absorption or desorption of moisture in simple units in which new fabric of known weight was encased in tire rubber, the experiments to be conducted at extremes of humidity. In the same laboratory the problem was approached from another direction by Wakeham, Honold, and Portas,[5] who made moisture determinations on cords removed from actual tires which had been exposed to various humidities.

Absorption Observations

Thin Rubber Pads

The usual methods for measuring the moisture permeability of wax paper, cellophane, etc., did not appear to simulate sufficiently conditions in a tire where fabric and rubber are molded together in intimate contact. Furthermore, while such methods had been used by Taylor, Hermann, and Kemp[6] with considerable success to study the water permeability of thin rubber sheets, it was questionable whether sufficient quantities of moisture would be transferred through relatively thick layers of rubber in an acceptable period of time, to be detected by these methods. Hence a method was devised in which pads or blocks of rubber, each encasing a piece of dry fabric of known weight, would serve as permeability cells and could be stored in a humid or arid atmosphere. The expectation of a small moisture transfer through the rubber dictated the use of extreme humidity conditions so that maximum changes in weight due to moisture could be recorded.

Selected for the present tests were three different tire fabrics:

Co-1445, SxP cotton, 22.75/4/3 cord, spun at Southern Regional Research Laboratory

Co-1446, A commercial rayon, 1100/2, 480 denier singles

Co-1447, Cotton, commercial fabric

The fabric samples were cut into squares about five inches on a side and were then placed into weighing bottles, in which they were dried and weighed. They were kept in the bottles until the moment for molding in the rubber. The stock for the latter was a GR-S tire-carcass material obtained from a commercial manufacturer of tires, rolled to a thin sheet and cut to fit a six by six-inch mold. Each fabric sample was molded between two rubber sheets (at 287° F. for 30 minutes), producing a pad about ⅛-inch thick, with a margin of solid rubber about ½-inch wide around the edges of the embedded fabric. To provide control measurements of the moisture absorbed by the rubber in the pads, a six by six-inch pad of solid rubber was also molded. On completion of each cure, the pad was placed into a desiccator over anhydrous $CaCl_2$ to cool to room temperature, after which it was weighed. With this procedure the dry weight of rubber and fabric could be accurately known. The pad consisting of pure rubber and the one containing the commercial fabric, Co-1447, were molded in duplicate, to provide checks in the moisture measurements. In Table 1 the actual dry weight of the rubber in each pad is given, along with the original dry weight of the fabric.

Table 1. Initial Dry Weights of Rubber and Cord Fabric in Thin Rubber Pads

Pad	Encased Fabric	GR-S (Grams)	Fabric (Grams)
"B"	None	74.110	....
"C"	Cotton, Co-1447	75.883	8.832
"D"	Rayon, Co-1446	77.869	5.693
"E"	Cotton, Co-1445	81.397	7.729
"F"	None	77.574	....
"G"	Cotton, Co-1447	81,537	8,260

The dry pads were placed on racks over water, in desiccator jars, thus being at approximately 100% relative humidity. Temperatures were in the range 75 to 77° F. Daily, at first, the pads were removed individually from the jars and weighed to determine the absorbed moisture. The progressive absorption of moisture was followed for about 200 days in Pad "B", the solid rubber pad, and Pads "C", "D", and "E", containing fabrics Co-1447, Co-1446, and Co-1445 respectively. Pads "F" and "G", the duplicates of "B" and "C", were kept in another jar; their gains in weight were recorded for a period of about 160 days. Toward the end of the storage periods, when the trend of the moisture absorption had become quite well established, weighings were made weekly.

The results on each of the pads, expressed as moisture regain in percent. of the dry rubber weight, are shown graphically in Figures 1 and 2. It will be seen that after the initial induction period the absorption of moisture tends to become linear with time, in all of the pads, and is still proceeding after 200 days in the humid atmos-

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[3] Southern Regional Laboratory, U. S. Department of Agriculture, New Orleans, La.
[4] For examples, see J. H. Dillon and I. B. Prettyman, *J. App. Phys.*, 16, 159 (1945).
[5] H. Wakeham, E. Honold, and H. J. Portas, India Rubber World, 113, 659 (1946).
[6] *Ind. Eng. Chem.*, 28, 1255 (1936).

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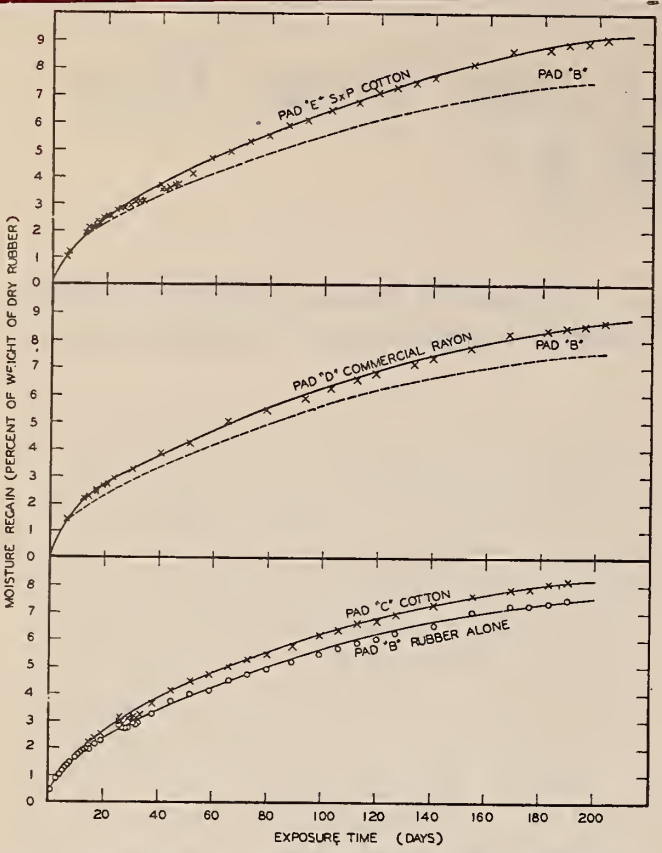

Fig. 1. Moisture Regain of GR-S Carcass Stock Pads Containing Cotton and Rayon Fabrics, Stored at 100% R.H. in Jar with All-Rubber Pad "B"

phere. There is sufficient downward trend to the slopes of the curve in the graphs, however, to suggest that the moisture regains are approaching a saturation value. While the general shape of the curves suggests a logarithmic relation between regain and time, a graphical test proves that this relation does not prevail.

As has been indicated, all the pads (both those containing fabric and those wholly of rubber) were of the same external size and shape. With the rubber pressed around and between the cords, the single layer of fabric in the pads was effectively of negligible thickness. Table 1 shows the mass of rubber displaced by the fabric specimens to be so small as to be masked by other experimental variations. Thus we may suppose that the overlying layers of rubber in the fabric-containing pads provided the same spatial conditions for the penetration of moisture into the rubber as was provided by the two layers of rubber on either side of a hypothetical middle plane in the all-rubber pads. The presence of a hydrophilic material at the middle plane evidently introduces differences between water-vapor flow in one system and that in the other, in spite of the geometric equivalence. It has been supposed, however, that this factor diminishes in importance as equilibrium is approached, and that even over the whole period of moisture absorption, a reasonable, approximate indication of moisture conditions in the rubber surrounding the fabric would be given by the moisture-absorption history of the all-rubber pads.

Accordingly, from the smooth curves in Figures 1 and 2 values of moisture regain at various times were re-

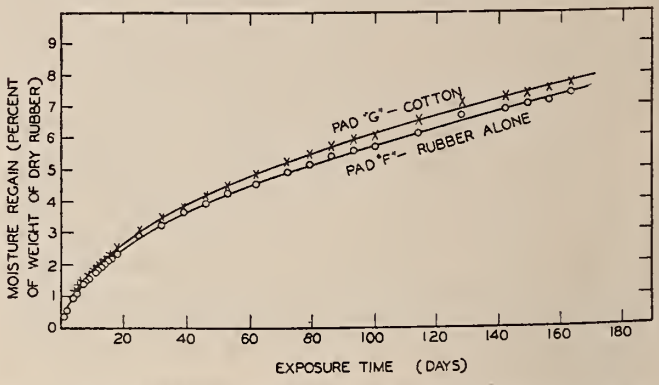

Fig. 2. Moisture Regains of GR-S Carcass-Stock Pad "G" Containing Cotton Fabric and All-Rubber Pad "F", Stored Together at 100% R.H.

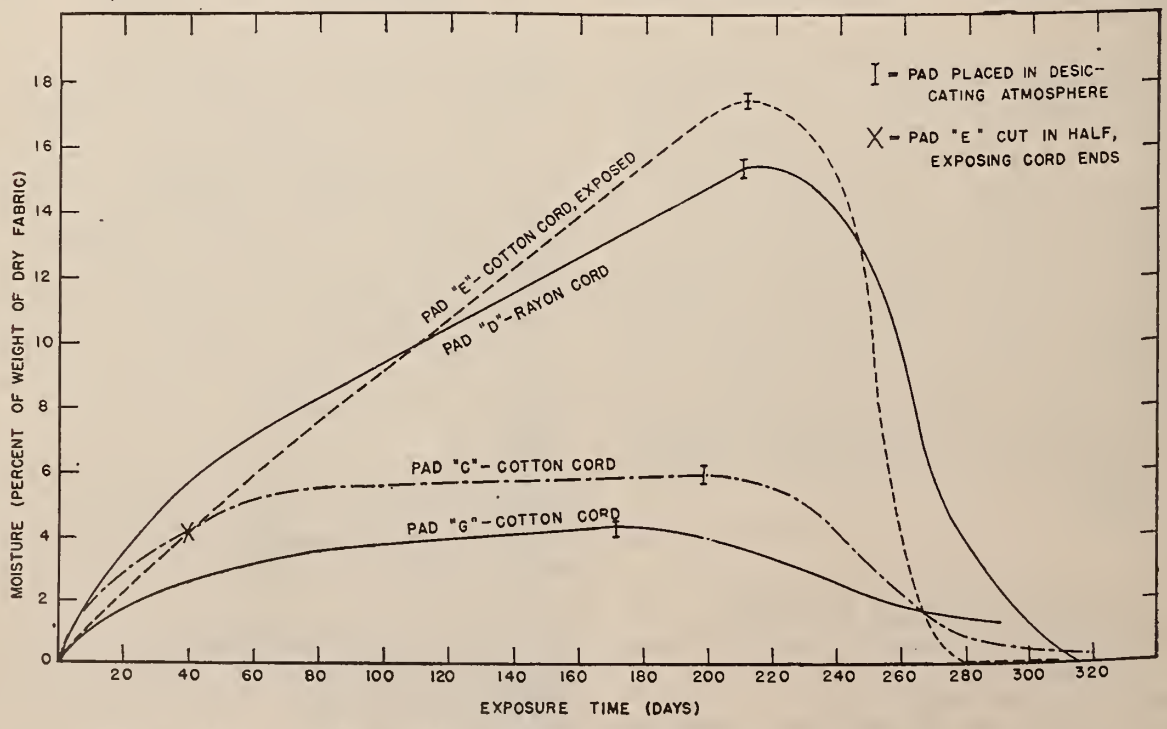
I = PAD PLACED IN DESICCATING ATMOSPHERE
X = PAD "E" CUT IN HALF, EXPOSING CORD ENDS
MOISTURE (PERCENT OF WEIGHT OF DRY FABRIC)
PAD "E" – COTTON CORD, EXPOSED
PAD "D" – RAYON CORD
PAD "C" – COTTON CORD
PAD "G" – COTTON CORD
EXPOSURE TIME (DAYS)

Fig. 3. Moisture in Fabrics in GR-S Tread-Stock Pads First Exposed to 100% R.H. and Then Transferred to Jars Containing $CaCl_2$

corded for each pad. The differences between these values and those for Pad "B" or Pad "F" at corresponding times, were then plotted. Through the plotted points smooth curves were drawn, representing the moisture taken up *by the fabrics*, expressed in percent. of the dry weight of rubber in each pad. By multiplying the ordinates of these graphs by the ratio of dry weight of rubber in the pad to dry weight of fabric, the basis for expressing moisture regain was converted to percent. of weight of dry fabric. The curves for the first 160 to 200 days in Figure 3 were thus obtained. These being derived curves, there are no appropriate "experimental" points to plot.

In Figure 4 are shown for comparison the moisture regains of bare fabrics exposed for 20 days to approximately 100% relative humidity. The specimens used here were from the same samples as those embedded in rubber, discussed above. The comparison of these results with those in Figure 3 brings out clearly the retarding effect of the enveloping rubber on the moisture absorption.

It will be observed that the linear character of the curves in Figure 3 after the induction period is more marked than in those of Figures 1 and 2. This practical linearity would seem to be due to the high absorptive capacity of the fabric, which is indicated in Figure 4. The moisture absorbed by the rubber embedded fabrics, even at 200 days, is still much below the amount they are capable of absorbing. The moisture in the rubber, on the other hand, may be supposed to be approaching its saturation value after 200 days, thus accounting for the diminishing slope of the curves for the whole pads in Figures 1 and 2. The well-known fact that rayon is more hygroscopic than cotton is reflected in the results shown in Figure 3. After 200 days the regain of moisture transmitted through the rubber is about 15% of the cord for rayon fabric (Pad "D") and about 5% of the cord for cotton (Pads "C" and "G"). The differences between the curves for Pads "C" and "G" have no known significance other than non-uniformity between the specimen materials. The ordinates in Figure 3, it must be remembered, represent small differences between comparatively large, observed quantities. As Figures 1 and 2 show, most of the moisture taken up was absorbed by the rubber envelopes, though, because of the mass of rubber in each pad, this moisture after 200 days amounted to only about 8% of the dry rubber weight.

In the Pads "C," "D," and "G" the moisture absorbed by the fabrics had to traverse layers of rubber about 1 16-inch thick on either face of the fabric. However in Pad "E," which was cut in half after being in the humid atmosphere for 39 days, the cord ends were exposed directly to the moist air, affording immediate access of the water molecules to the fabric. The result is indicated in Figure 3 in the steep ascent of the moisture-regain curve for this pad.

Desorption measurements on these same pads are discussed below.

Rubber Blocks

The foregoing results indicated that a test piece consisting of fabric encased in rubber provided a feasible means for obtaining a measure of the permeability of rubber to water vapor. The results can be interpreted with reference to cord in a tire with less artificiality than can the conventional permeability tests. It was recognized, however, that in the flat pads the thinness of the rubber layer separating the cord from the ambient atmosphere provided a somewhat more favorable condition for the transfer of moisture than prevails for most of the cord fabric in a typical tire. Accordingly, to bring the experiments into closer semblance with a tire, it was decided to prepare test pieces in which the wall of rubber encasing the cord would be substantially increased. It appeared also that a larger ratio of fabric to rubber than had been used in the thin pads would be more representative of the proportions in a tire, especially of the heavy-duty type.

In planning the experiment to utilize the most suitable available mold, it was decided that the rubber test-blocks be three by four by one inch, and that they initially contain a rectangular cavity in which a bundle of cord would be placed. It was estimated that after curing, the cord bundle would be surrounded by a wall of rubber from ¼- to ½-inch thick. While this type of test piece would provide the desired relations between fabric and enveloping rubber, it was recognized that unlike the case of the thin pads, the moisture conditions in the rubber of the blocks could not be duplicated even approximately by those in an all-rubber block. An appreciable volume of the block would be occupied by the cord and void spaces in the bundle. It was thought, however, that it would be instructive, yet not inconvenient, to carry along in the experiment some all-rubber blocks, to secure an indication of the moisture behavior of a compact mass of GR-S, as contrasted with that of a thin pad.

Two cords, as follows, were used in preparing the test blocks for this part of the study:

Co-752, Stoneville 2B cotton, 23/4/3 cord, spun at Southern Regional Research Laboratory

Co-1766, Rayon, high tenacity, 1100/2, furnished by commercial manufacturer

Estimates were made of the lengths of cord required, and when these were cut each cord was wound into two compact bundles. The bundles were placed into weighing cans, dried for two hours at 105° C., and weighed in the conventional manner. In order to reach a judgment as to whether the cords would pick up an appreciable amount of moisture on transfer to the mold in the subsequent curing operation, the bundles (after the above-mentioned determinations) were exposed for one hour to the air of the room in which the mold was to be loaded. On reweighing the bundles, it was found that during exposure the average rate of absorption was seven mg./min. for the cotton, and six mg./min. for the rayon, or approximately 0.02% regain/min. for either fiber. While it was recognized that the initial rate would be higher, it was concluded that with rates of this order of magnitude, no appreciable error due to absorbed moisture would be introduced during the building of the rubber blocks. After this test the cords were redried and again weighed, with the results given in Table 2. They were kept in the dry condition until molded in the test blocks.

Table 2. Initial Dry Weights of Rubber and Cords in Rubber Blocks

Block	Encased Cord	GR-S Grams	Cord Grams
"H"	Cotton, Co-752	151.502	37.209
"I"	Rayon, Co-1766	161.588	35.143
"J"	Rayon, Co-1766	159.300	35.387
"K"	Cotton, Co-752	162.061	37.589
"L"	None	120.981	....
"M"	None	122.145	....

The rubber used for the blocks was a GR-S stock from the same source as that used in the above-described experiments. The stock was rolled to a thickness of ¼-inch and cut to fit a mold cavity six by eight by one inch, after the weight of raw stock required to give a full mold on curing had been predetermined. Four layers of the rubber sheet were used; the middle layers

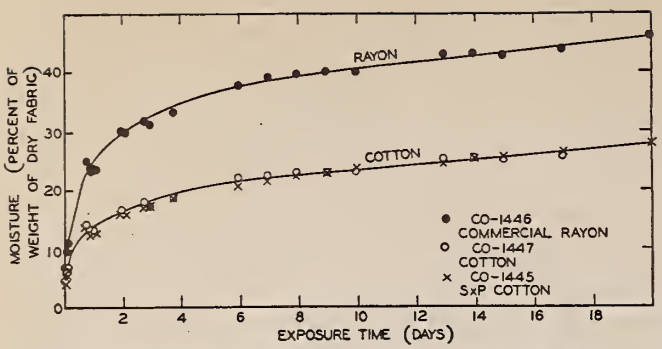

Fig. 4. Moisture Regain of Bare Fabrics Used in Present Experiments, Exposed to 100% R.H.

had rectangular openings two by three inches into which the four bundles of fabric were placed. The mold was preheated for 30 minutes and was loaded and closed as quickly as possible to minimize absorption of atmospheric moisture by the cords. After a 45-minute cure at 287° F. the rubber was tested for hardness with a durometer. An undercure was indicated; so the rubber was further cured for another 45 minutes at the same temperature; the hardness then was found satisfactory. This large molded slab was cut into quarters approximately three by four inches, each containing a bundle of the sample cords. The cords were thus encased in walls of rubber from ¼- to ½-inch thick. Precautions were taken, as in the experiments with the thin pads, to keep the blocks dry before they were finally weighed.

From these weighings, together with the weights of the cords previously obtained, the data in Table 2 were derived.

From a slab of solid rubber cured in the same mold under the same conditions, two blocks about two inches square by one inch were cut. These, blocks "L" and "M," were used to obtain measurements on moisture absorption by the rubber. Their dry weights also are entered in Table 2.

The conditions of storage of the six blocks at approximately 100% relative humidity, as well as the weighing procedure, were essentially the same as those described for the thin pads. Observations were made on all blocks over a period of more than one year.

The results are presented graphically in Figure 5. Since they would be of no help in the better location of the curves, but rather would obscure each other, the plots of several of the observations on each block made in the early days of the experiment have been omitted. The moisture regains calculated for the solid rubber blocks "L" and "M", for each of the days on which readings were made, so closely duplicated each other that their plots over most of the range were indistinguishable on the graph. Accordingly, one curve is used to represent the data for both blocks. The rather large discrepancy between regains in blocks "H" and "K" containing cotton cord, like that between Pads "C" and "G," must be charged to non-uniformity.

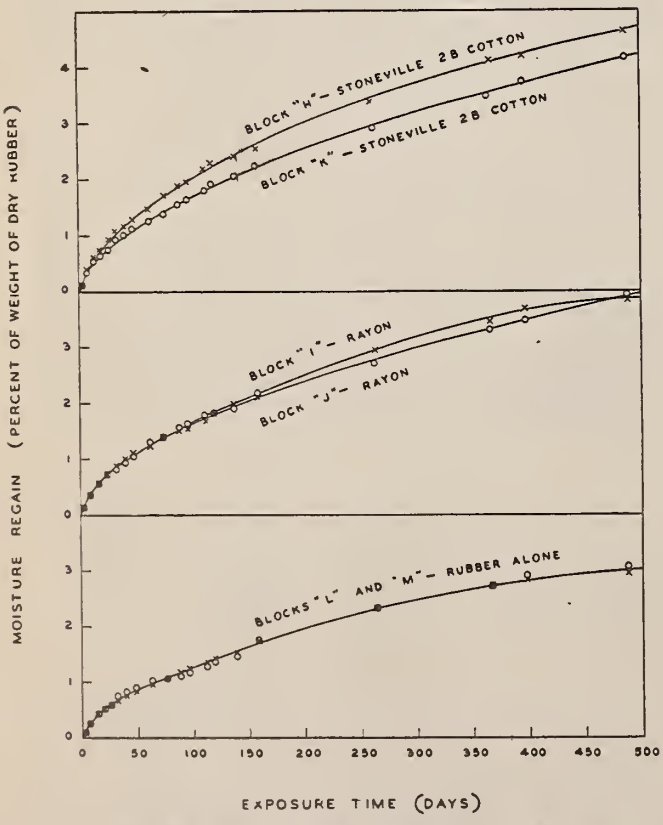
BLOCK "H" — STONEVILLE 28 COTTON
BLOCK "K" — STONEVILLE 28 COTTON
BLOCK "I" — RAYON
BLOCK "J" — RAYON
BLOCKS "L" AND "M" — RUBBER ALONE
MOISTURE REGAIN (PERCENT OF WEIGHT OF DRY RUBBER)
EXPOSURE TIME (DAYS)

Fig. 5. Moisture Regain of GR-S Tread-Stock Blocks Containing Cotton and Rayon Cords, and Containing No Cord, Stored at 100% R.H.

Fig. 6. Half-Sections of GR-S Carcass-Stock Blocks, Showing Arrangement of Cotton and Rayon Cords in Rubber; The Blocks Were Cut at Mid-Section after Completion of the Moisture Absorption Experiment

While Figure 5 is useful in showing the trends of moisture absorption in a thick rubber-and-fabric structure, the data reproduced there, as has been indicated, were not suitable for estimating moisture regain in the fabric, as was done for the thin pads. A direct determination of fabric moisture was made on all four blocks containing the cotton and rayon cords, after 492 days of storage. The blocks were cut open; cord was pulled from one half of each block, placed into a tared moisture dish, and weighed immediately. The time elapsing between cutting and weighing was probably less than one minute, so that the moisture regains thus found are believed to be those of the embedded cords to good approximation. The results are given in Table 3;[7] while sectional views of the cut blocks are shown in Figure 6.

Table 3. Moisture Regains of Cords Removed from Rubber Blocks Exposed to 100% Relative Humidity for 492 Days

Block	Fiber	Moisture Regain %
"H"	Cotton	6.6
"I"	Rayon	7.2
"J"	Rayon	7.7
"K"	Cotton	5.6

The moisture regains for the rayon here are in contrast to the 15% shown in Figure 3 by the rayon cord of

[7] It is of interest to note that use, on the data for 488 days in Figure 5, of the estimation method used on the thin pads when applied to rubber block samples, gives 6.7 and 5% regains for cotton (Blocks "H" and "K," respectively) and 4.0 and 4.1% for rayon. The agreement with Table 3 on cotton is surprisingly good.

pad "D" at only 200 days. There is tolerable agreement, however, between the regains in the cotton cords removed from the cut blocks and those deduced from observations on the thin pads. In fact, results in Table 3 on cotton cords, indicating about 6% moisture regain after 492 days, confirm a suggestion from the results on the cotton cord in pad "C," indicated in Figure 3, *viz.*, after about 5½% moisture regain is attained, the rate of absorption drops sharply to a very small value. Both regain values agree fairly well with the 5.0 to 6.6% moisture regains found by Wakeham and co-workers[5] in the well-encased outer plies of cotton-fabric tires stored under conditions comparable to the present ones. These data suggest that as the regain of the embedded fabric reaches a certain value (apparently about 6% for cotton), the difference between vapor pressures in the humid ambient air and at the fabric, driving moisture through the rubber, is reduced to such an extent that it is nearly or wholly counterbalanced by hydrophilic forces in the rubber envelope. Thus a state might be reached where slowly declining hydrophilic forces in the rubber permitting only slow diffusion of moisture to the fabric are in near-equilibrium with the pressure head, also slowly declining because of the absorption of moisture by the fabric.

Conclusions on Moisture Absorption

It is not possible to derive from the results of the present experiments a reliable quantitative law regarding the dependence of water-vapor permeability of GR-S on thickness. One reason is that the amount of moisture transmitted through the rubber in a given time of exposure depends on the material of the fabric, as Figure 3 shows.

Secondly, the thin pads and the blocks which would provide different wall thicknesses on which to base calculations, also differ in shape and in proportions of fabric and rubber. These factors independently influence moisture transmission significantly.

An indication of the influence of increased thickness of rubber on moisture penetration is given by comparison of the lower graph in Figure 5 with that of pad "B" in Figure 1. Thus the thin rubber pad "B," ⅛-inch thick, absorbed 7.5% moisture in 200 days; while the blocks "L" and "M," eight times as thick, but only 1.6 times as massive, absorbed only 2% moisture in the same time. The exposed specific area (area per unit mass of rubber) was, of course, much greater in the pads than in the blocks, being approximately 6.5 and 1.2 sq. cm./gm., respectively.

Permeability measurements, such as were made by Taylor, Hermann, and Kemp,[6] involving unidirectional flow through natural rubber sheets, indicate that thick samples are not so impermeable to moisture as the inverse-thickness law would indicate. Nevertheless a substantial reduction in moisture penetration is achieved when the thickness of rubber is increased and the surface-to-volume ratio is decreased, as comparison of the present results on the solid rubber pads and blocks, as well as on rayon in Figure 3 and Table 3, indicates. We may still expect that the moisture content of fabrics in heavy bus and truck tires, having a thicker outside layer of rubber protecting the fabric, would be much less responsive to ambient moisture conditions than would that of fabrics in passenger-car tires.

Desorption Observations

Alternating with periods of service in which tire fabrics tend to pick up moisture are periods in which the tendency is for the moisture content to drop. This situation arises when tires are run at temperatures above, say, 200° F. To the extent allowed by the water-vapor permeability of the encasing rubber, the moisture contents of the fabrics and their dependent mechanical properties will reflect the alternations in the ambient humidity conditions. Because of the numerous factors entering into the moisture-transmission behavior of the rubber-fabric system, it cannot be concluded *a priori* that the rate of desorption of the fabric in a desiccating atmosphere will be the same as that of absorption. To obtain experimental information on this phase of the problem, measurements were undertaken on the loss of moisture by rubber-encased fabrics placed in desiccators.

The six pads, labeled "B" through "G," which had been stored at 100% relative humidity in the above-described tests, were transferred to desiccators charged with calcium chloride. The air in these jars may be assumed to have quickly attained a relative humidity within a few percent. of zero. The pads, after being put into the desiccating atmosphere, were weighed daily at first, but in the latter part of the experimental period they were weighed weekly. The present experiment covered a period of 101 days. As in the moisture-absorption experiments, the amount of moisture remaining in a pad on a particular day, considered as moisture regain, was converted to percentage of the weight of the dry rubber. The results, so treated, are presented graphically in Figure 7.

It will be seen that the pads of rubber alone reached practical equilibrium with the dry environment in about 35 days; while at the end of 100 days the moisture in all pads dropped to 0.25% or less. The slower rate of loss of moisture in the pads "C," "D," "E," and "G" is evidently associated with the presence of the fabric in them. However the difference on a particular day between the ordinates of the two curves in each panel of Figure 1 is not to be taken directly as the moisture in the fabric on that day. Actually, some of the moisture represented by this difference must be in the rubber, for (except in pad "E," which was cut in half) all the moisture lost by the fabric must transpire through the rubber. This is to say, in effect, that the moisture in the rubber in pads "C," "D," "E," and "G" does not actually follow the curves for pads "B" and "F," but, rather, curves lying between the two which appear in each panel of Figure 7. Thus there is no increase in fabric moisture for the first 10 or 20 days, as would be the apparent conclusion if the mere differences in ordinates were taken as fabric moisture. The increases in these differences during the first days of exposure are clearly evident in Figure 7; after about 25 days the differences diminish.

There is no evident reason, however, for a prolonged increase in fabric moisture when the pads are transferred from the humid to the dry atmosphere. For a brief period, continuing (but rapidly diminishing) diffusion of moisture from rubber to fabric may be expected. After 200 days at 100% relative humidity, however, the moisture in the rubber and that in the fabric may be supposed to be in practical equilibrium so that the pressure driving moisture from rubber to fabric is negligible. Hence, to arrive at an approximation to the actual distribution of moisture between rubber and fabric during the course of the drying period, it was assumed that the fabric moistures given by differences at the end of the high-humidity exposure were the ones actually prevailing. When the pads were placed in the dry atmosphere, the fabric moisture gradually started to decline; the rate increased with time. After a certain

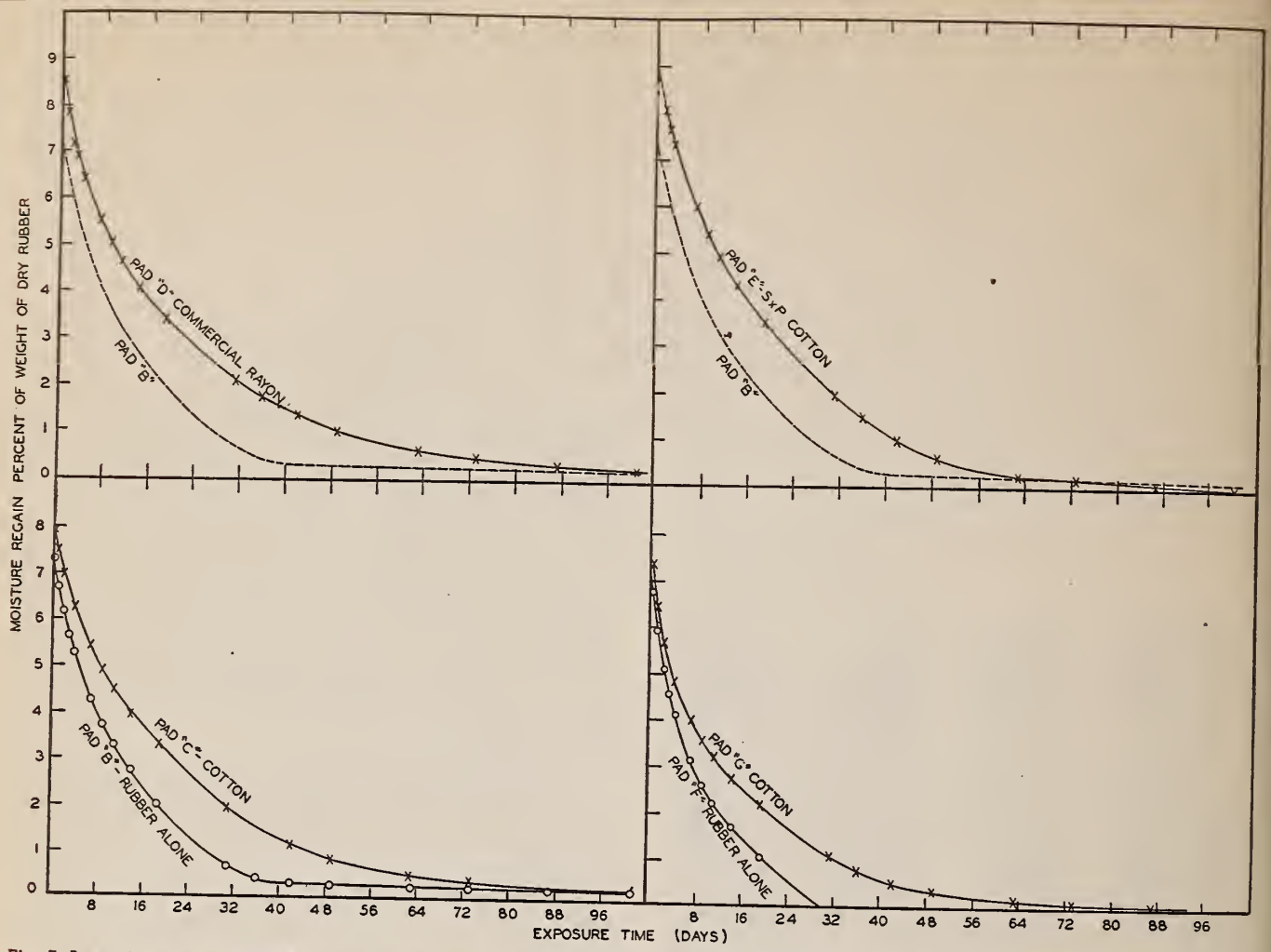

Fig. 7. Loss of Moisture by GR-S Carcass-Stock Pads Containing Cotton and Rayon Fabrics, Stored in Jars Containing $CaCl_2$, after Storage at 100% R.H.

number of days (varying from pad to pad) the excess moisture (in percent. of dry rubber weight) associated with the pads containing fabric was found to have dropped appreciably below its value at the start of the desiccation. From this point to the end of the experiment this excess was taken as the fabric moisture in each pad. More rigorous interpretation of this excess is that it is the upper limit on the fabric moisture. The moisture in the fabrics, as given by the above analysis of the data, is shown in Figure 3, along with that obtained previously for the storage of the pads at 100% relative humidity.

As would be expected, pad "E," in which the cord ends were exposed directly to the desiccating atmosphere, shows the most rapid loss of moisture, dropping to around 1% in about two months. The rayon cord in pad "D" shows the next most rapid decline in moisture. About 85 days are required for the moisture in the rayon fabric to drop to 2%. The cotton fabric in pad "G" requires about an equal period to attain the same percentage of moisture, though it contains only 4% moisture regain, as compared to nearly 16% in the rayon fabric at the start of the drying experiment. About 60 days are required for the moisture in the cotton of pad "C" to drop from 6 to 2%.

Conclusions on Moisture Desorption

It is readily apparent from Figure 3 that both cotton and rayon fabrics embedded in rubber desorb moisture more rapidly than they absorb it, under the extreme humidity conditions used in these experiments. Wakeham and co-workers[5] found similar behavior in the moisture of sealed-off tire sections. They, however, employed a higher temperature (185-200° F.), and accordingly found that the tire sections dried to equilibrium with 2% relative humidity in about 25 days. Considering that the present experiments were conducted at around 75° F., the two sets of observations are to be regarded as confirmatory.

The present results indicate also that while an embedded rayon fabric picks up a large amount of moisture, as compared to cotton, under arid conditions it loses this moisture much more rapidly than does cotton, even at equal moisture regain. The cotton fabric exhibits inertia with respect to moisture sorption, taking up moisture more slowly than the rayon, and then holding the moisture more tenaciously when it has been absorbed.

General Conclusions

Certain conclusions regarding probable moisture conditions in the fabrics of tires in actual service may be drawn from the present experiments.

(1) The results indicate clearly that the 2-4% moisture which cords are generally supposed to have at the time the tire is fabricated cannot be regarded as a permanent condition. The carcass rubber, very evidently, is not an impermeable envelope.

(2) In passenger-car tires in which the outer layer of

rubber in the sidewalls is on the order of 1/16-inch thick, the moisture in the outer plies of a cotton fabric may be expected to amount to 6.0 or 7% when the tires have been in service for six months in a damp climate (say 70 to 75% relative humidity).

(3) It appears that under the conditions of *thorough, deep* embedment in rubber, cotton cords at normal temperatures, absorb moisture very slowly above about 6% regain, even when the rubber envelope is exposed to 100% relative humidity. These conditions are fulfilled by the cords in most of the plies of heavy-duty bus and truck tires.

(4) If breaks occur in the outer rubber, and the tires are generally used on wet pavement or poorly drained roads, the moisture regain may be expected to rise to 12 or 14%, as our results on pad "E" suggest.

(5) Under the same conditions outlined in the above conclusions, the moisture in *rayon* fabrics could be expected to be from 20 to 100% greater than the moisture in *cotton* fabrics.

(6) In normally dry climates (where the average humidity is in the range of, say, 20 to 45%) it would appear that the original moisture in the fabrics of undamaged tires would remain substantially unchanged for an indefinite period.

(7) Through a cycle of exposures to humid and arid atmospheres, the time-average moisture regain of rayon fabric would appear to be about three times that of a similarly encased cotton fabric.

The foregoing conclusions receive added weight from the fact that they are in agreement with the results of the Wakeham[5] group. The two series of experiments are complementary in that Wakeham used actual tire sections, which, however, necessitated complicated experimental procedures; while in the present study the geometry of the test pieces had little resemblence to that of a tire, but was sufficiently simple that direct methods could be employed to follow the complete moisture history from curing onward.

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